Testing the geographical data streaming platforms required for the 21st Century food system using an industry ecosystem approach.

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Highlights

- This research determines how large geographical datasets can be integrated with social, economic and environmental conversion factors to provide incisive guidance to companies who wish to improve supply chain practice.
- This is achieved by determining the most useful content for specific algorithms that can assess connectivity and impacts of supply chain practices and enhance responsible consumption.
- The methods utilised are those familiar to standard geographical analysis of data but it is the emergence of data streaming platforms and Distributed Ledger Technologies that are enabling the scaling of these contents to supply chain and population or meta levels so that they are relevant to business.
- The major finding is that geographical methods can enhance the communication of sustainability and connectance claims for provenance of food and beverage

products. The outcome in achieving this will be enhanced trust associated with food and beverage Fast Moving Consumer Goods.

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Abstract

Testing the planning of resource utilisation across food supply chains provides sustainability and security reporting that can resonate with consumer requirements. The research reported here demonstrates this approach for fast throughput convenience foods that have short shelf life and whose product development must be agile enough to meet changing consumer demand. The higher-level outputs of these conditions are the responsible reporting of nutritional, greenhouse gas emission and packaging impact assessments. Together with the food safety requirements of this food category, it means manufacturing operations are in some of the most challenging arenas for sustainability assessment. The analysis presented here shows that food production systems can no longer focus on one or two core conditions, such as food safety or quality. This is a strategy of least resistance that has previously worked but it continues to displace risks elsewhere within the food and beverage meta-system, rather than attempting to reconcile complexities and address intra-system root causes. By taking a holistic view the food ecosystem approach can inter-connect requirements using digital and externally linked platforms that will fundamentally change the way future food systems operate. The integration and streaming of these platforms is only achieved through innovation, with the end-user providing development and balance in emergent business ecosystems.

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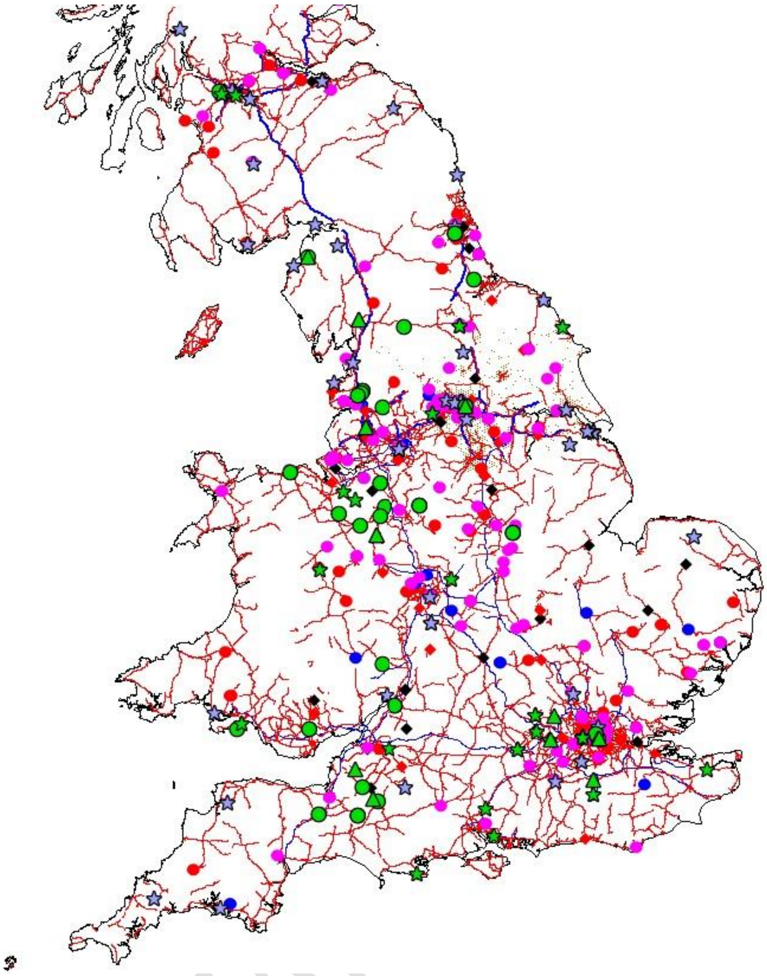
Graphical abstract



Keywords

consumer goods, supply chains, food, beverage

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1. Introduction

The term of business ecosystem brings with it a concern of overusing buzz words but the application of theoretical ecology to business systems is not unfounded and has an established legacy of application (Conway and Barbier, 2013). Many ecological models explain how simple equations can project chaotic outcomes in systems (Nowak and May, 1992). Extending this to markets has pretty much defined food system modelling works of the last ten years (Chen et al., 2018; Ingram et al., 2013). The reiteration of combinations of a rate of growth against a carrying capacity of a system has led to some of the most useful models used over many decades for maximum sustainable yield in fisheries, competition cycles that determine commercial risk and epidemiological models that enhance biosecurity (Conway, 1977). The use of modelling has potential to project demand and consumption in food systems because they enable a greater understanding of how populations respond to change (Martindale, 2017).

The need for new approaches in projecting consumption is required because the use of trend data to develop new products is becoming erroneous and there is a high possibility of failure when launching new food products (Bogoni et al., 2019). Thus, trend data, which are typically developed by scouting for products that are preferred at specific times in retail arenas, enable firm to collect data about consumers' preferences and needs (Busse and Siebert, 2018). Moskowitz and Saguy, 2013, demonstrate how these data could be categorised as consumer involvement data, food trend data, and environmental factor data. Social media communications have changed how firms obtain data and a better understanding of consumer requirements will reduce business investment risks. New digital applications (e.g. internet, online consumer survey) are being used for efficient data capture from consumers and they can be scaled and secured across supply chains. This calls for a more proactive approach (e.g., modelling or simulation) that has already been tested calling

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for the "continuous collection and assimilation of suitable information about the consumers' views and needs during product development" (Costa and Jongen, 2006).

This is important because the food and beverage industry in Europe is facing unprecedented pressure points that have been exposed by weather events, reduced quality, and supplier reconciliation issues (Van Passel et al., 2017). These restrict the supply of fresh produce, frozen meats and secondary resources such as food grade ingredients. These go relatively un-noticed save for temporary press and social media reports of crisis but they are defined in assessment of supply chain performance where the industry shows resilience that protects the European consumer from adverse impact and food price volatility (Jack et al., 2018). However, resilience will not be limitless, and the current food system status is quite simply summarised as, innovate or fail and the identification of processes that can reduce resilience in supply chains such as extreme weather and changes in skill acquisitions must be characterised and understood. Given the limits to resilience in supply chains, circular economy (CE) has received increased attention as it is able to overcome conventional consumption and production trend and increase resource performance (Ghisellini et al., 2016). Using principles and theory from industrial ecology, CE promotes the closing-the-loop production model, increases resource efficiency, and reduce pollution levels (Jurgilevich et al., 2016). It harmonises environment, economy, and society as it lowers the consumption of resources in the production and wastes into the environment (Noya et al., 2017).

The research here develops an understanding of latent processes by identifying routes to the following; (1), the complete use of raw materials and recirculation of resources within circular economies (e.g. production of insect larvae for animal feeds); (2), the use of big data that enables the development of fit for purpose sustainability metrics for food product

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assessments; and, (3) the redesign of ingredient production using localised and urban farming for local high value and assured products (e.g. vertical farming). The convenience foods categories are most likely to experience any adverse impacts because they are the primary examples of Fast Moving Consumer Goods with limited shelf life and significant consumption risks if supply chain derived abuses of quality and safety occur (Martindale et al., 2018b).

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2. Material and methods

The research presented here uses Geographic Information Systems (GIS's) to present supply chain models and it identifies where digital technologies and blockchains can enable innovations that deliver sustainable foods. The research has been developed using data derived from open-access datasets described here that have been geocoded so that location modelling is made possible for resource planning and respective sustainability and security assessments. MapInfo 17.02 software was used to plot geographic data using Edina Agcensus services for the Agricultural and Horticultural Survey (AHS) at 5 km^2 grid resolution[1] and the fame business databases[2]. The AHS is geocoded every ten years and the latest data for this research was 2010, this was used to plot cereal production intensity. The fame database provides business postcodes which were geocoded to six figure grid references for geographical plots. The fame databases only provides the registered office geo-locations and those companies who publicly report their business information. It is within these limitations that the models presented in this research are made. The geographic area analysed was Great Britain because the Edina Grid square agricultural census data is only collected for England, Scotland and Wales in this research.

A logistics survey was carried out for 34 food Small Medium sized Enterprise (SME's) companies in the Yorkshire and Humber Region of the UK obtain data on food loads transported and destinations. The data obtained was confidential and anonymous so that social, economic and environmental conversion factors could be applied to food and beverage category transport footprint. The conversion constants derived for the cost and CO_2 emissions associated with food miles are derived from a white paper reported to Defra by Smith et al., 2005. The crop production areas and livestock numbers used for GIS models

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[1] See, Edina Agcensus (2019) http://agcensus.edina.ac.uk/ (accessed 27th November 2019)
[2] See, fame, https://www.bvdinfo.com/en-gb (accessed 20th December 2019)

were obtained from the Agricultural and Horticultural Survey (AHS) dataset[3]. The crop production yields were obtained from the Defra AHS and amounts of manures produced were determined using typical reported Defra RB209 manure volumes per animal. The datasets have important implications for planning the transport of inputs and products where the outcomes are the optimisation of fuel use and financial planning for growing seasons.

Connectance calculation methods were derived from the Gross et al., 2009 where connectivity assessment has been utilised to asses the redundancy of links in food webs. In this study, the total number of links in a system are presented as a proportion of the total number of combinations between functions in that system. This method has been applied here to food supply chains and the producer, processor and manufacturer functions in the food system. The conntectance represents the total number of links (l) that are possible divided by the number of possible combination of those links or n x (n-1).

$$C = {}^{L}\!/_{n(n\text{-}1)}.$$

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[3] See, June Survey of Agriculture and Horticulture, England https://data.gov.uk/dataset/332b5dfc-9616-47b2-81ee-4fcd407196ca/june-survey-of-agriculture-and-horticulture-england (Accessed 20th December 2019)

3. Results

Figure 1, shows a digitally generated map using Defra's Agricultural and Horticultural Survey for the geographic distribution of the sugar beet crop in the East of England, UK. **Table 1,** shows the production of animal manures within 20 km of the two sugar beet processing factories based in the East of England.

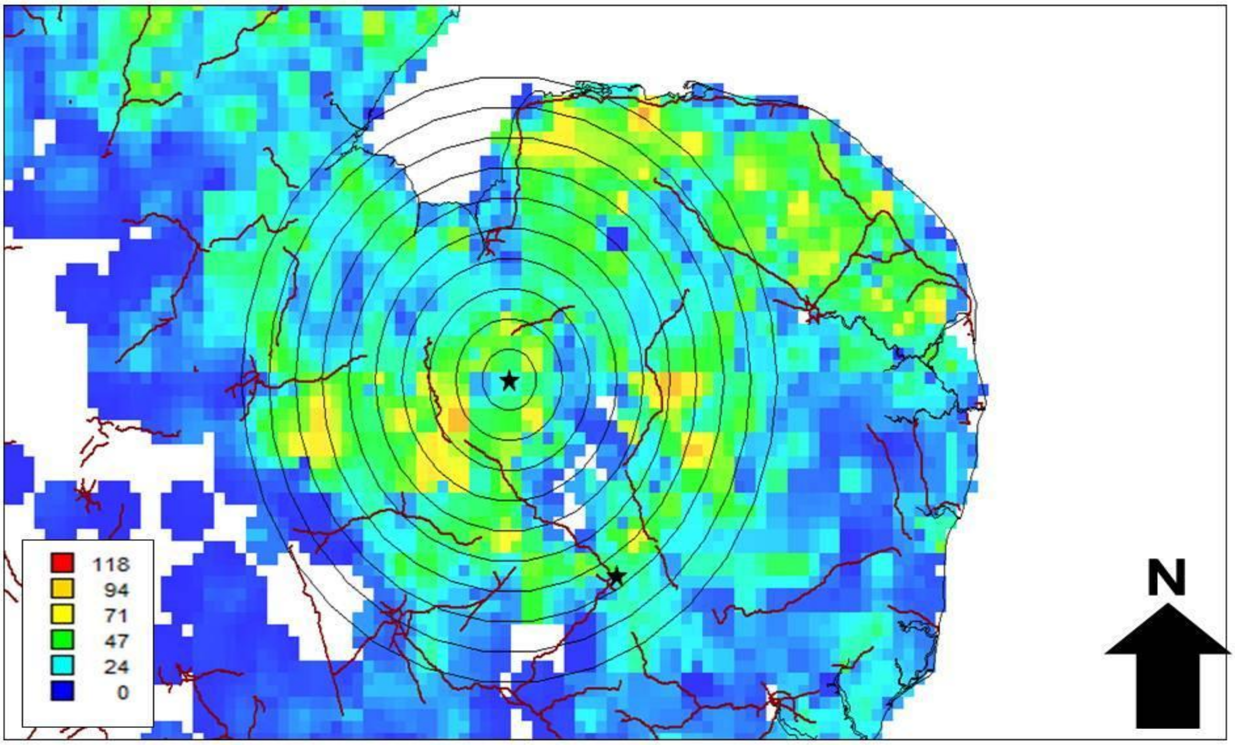

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Figure 1. The map shows the variation in the amount of land used for sugar beet production as a colour grid for the number of hectares of sugar beet per 2 km^2 (the colour grid key shown in the bottom left of the figure is hectares sugar beet per 2km^2). The Wissington and Bury St Edmunds factory sites are marked and the sugar beet data shown in Table 1 has been obtained from a 5 km concentric circle grid.

Table 1. The amount of sugar beet area and organic manure produced within 20 km of the Wissington and Bury St Edmunds British Sugar factories.

British sugar Factory	Agricultural production within 20 km of factory each year for;				
	Sugar beet (10^3 ha)	Dairy manure (10^3 t)	Beef manure (10^3 t)	Pig manure (10^3t)	Poultry manure (10^3 t)
Wissington	11.7	0.2	3.1	433.8	122.8
Bury St Edmunds	6.8	2.5	2.0	670.9	321.2

Table 2, shows the results of converting logistical data from 34 SME food companies into social, economic and environmental impact assessments for food transport. The sector summed values for distribution of products in a typical week. The companies and calculations were made for in February and October 2019, using raw data obtained by company logistics survey and the economic and environmental conversion factors reported by Smith et al., 2005.

Table 2. The sector summed values for distribution of food products in a typical week for 34 SMEs base in the Yorkshire and Humber region of England, UK.

	Prepared food (13)	Meat (10)	Veg and fruit (6)	Dairy and ice cream (5)
km	4463.6	3970.4	2294.9	3976.4
Loads per week	121.0	34.3	35.0	24.0
Load weight (t)	10.2	6.9	24.0	52.0
Temperature (°C)	40.0	-20.0	0.0	0.0
Diesel consumption food (l)	246.8	267.8	248.3	212.5
Diesel consumption (l)	4288.9	4460.6	4313.9	3692.6
CO_2 whole (kg)	11494.1	11954.5	11561.1	8473.0
CO_2 food (kg)	633.1	717.7	665.4	569.6
CO_2 cost (£)	19.3	17.6	10.2	17.6
Accident cost (£)	135.8	123.9	71.6	124.1
Congestion cost (£)	969.2	884.0	510.9	885.3
Transport infrastructure (£)	3.7	3.3	1.9	3.4
Noise cost (£)	24.8	22.6	13.1	22.6
Air quality (£)	44.1	40.2	23.2	40.2
Sum of social cost (£)	1196.8	1091.6	630.9	1093.2

The GIS methodology is developed for prepared meals using the fame business location database and wheat supply chains using the fame databases with the AHS database

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(**Figures 2a** and **b**). The prepared meals supply chain has been categorised to include vegetable, dairy, meat, poultry, seafood and dairy processors that supply ingredients. The wheat supply chain includes production data and mills because the supply chain is gated by mills which process wheat into flour and other ingredients. The food business geocoded models develop methods further because there is now a means to calculate risk of how much produce enters supply chains. An important aspect of project this is to assess the connectivity of different ingredient suppliers to food manufacturers.

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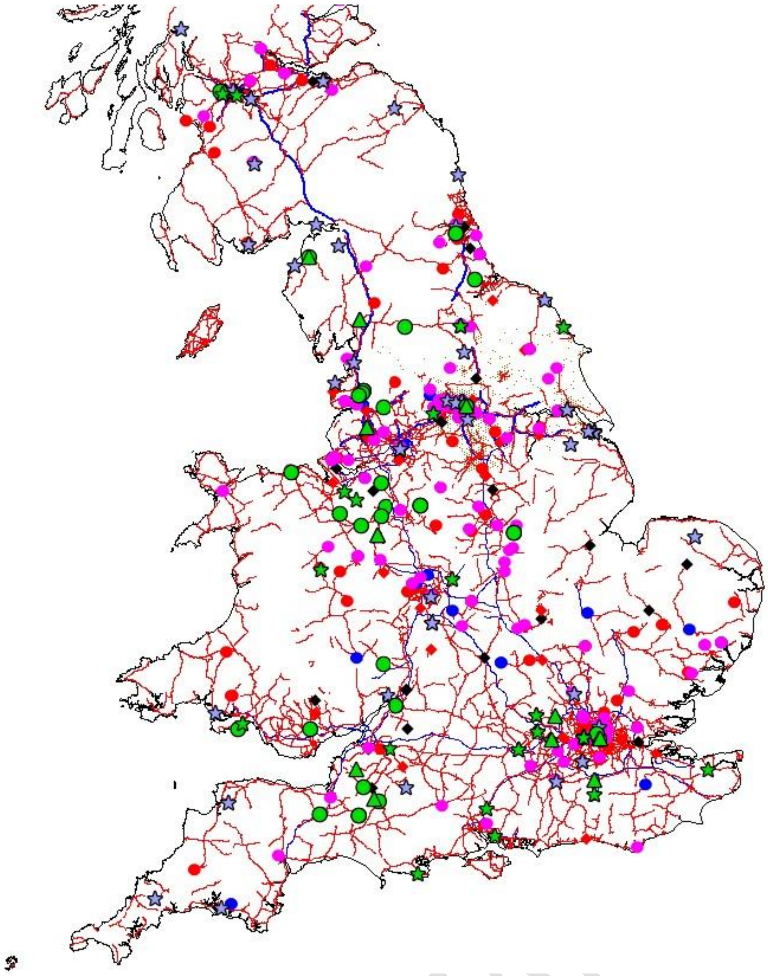

Figure 2a. A geocoded business location model for prepared meals, using the recorded location of meat and poultry producers (153 companies), seafood producers (77 companies), dairy product producers (Dairy products (77 companies) and prepared meals (54 companies)

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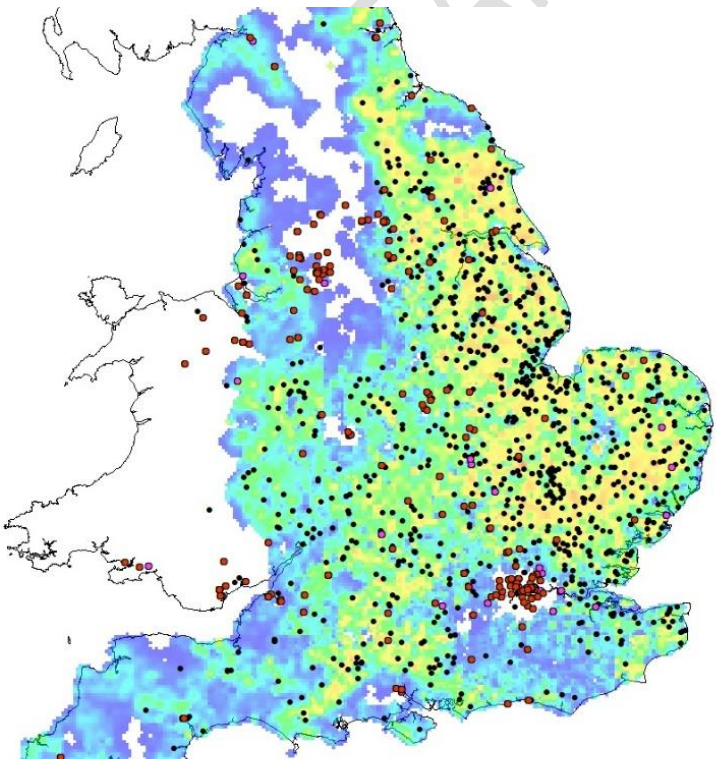

Figure 2b. A geocoded business model using the wheat production area from the AHS, cereal processors Cereal processors (1129 companies), Bakeries (291 companies) and mills (39 companies).

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Table 3-5, show the connectance as described by Gross et al., 2009, of dairy and meat producers (**Table 2**) and condiment and seasonings manufacturers (**Table 3**) to prepared meal manufacturers. **Table 4**, shows the connectance of cereal producers to cereal mills and cereal mills to bakers and blenders of cereal products.

Table 3. The connectance of dairy and meat producers with dairy and meat product manufacturers of Great Britain.

	Dairy (milk, ice cream, butter, cheese)	Meat (cattle, sheep, poultry)
Number of producers	1669	2095
Number of manufacturers	75	247
Total links, producers to manufacturers	125175	517465
Connectance, producers to manufacturers	0.045	0.118

Table 4. The connectance of condiment and seasonings manufactures to prepared meal manufacturers of Great Britain.

	Manufacturers
Manufacturers, condiments and seasonings	37
Manufacturers, prepared meals	54
Total links, ingredients producers to meal manufacturers	1998
Connectance, ingredients producers to meal manufacturers	0.698

Table 5. The connectance of cereal producers. Mills and cereal product manufacturers of Great Britain.

	Cereal mills and manufacturers
Number of cereal producers	397
Number of cereal mills	39
Number of manufacturers- bakers, cereals, pasta and pastry	289
Total links, producers to mills	7097
Total links, mills to manufacturers	4334
Connectance, producers to mills	0.045
Connectance, mills to manufacturers	0.052

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4. Discussion

The methods used in this research are not so complex their application will be limited and it is the ability to scale metrics and indices derived from them to whole populations and the ecosystem that make geographical assessments increasingly useful. Furthermore, the emergence of the requirement to qualify provenance and traceability of food and beverage products means there is typically a geographical component associated with their data. Blockchain systems enable the locking in of both analytical information and geographical or transaction data in an assurance system. As an example, the typical type of analysis used to assess geographical data in a supply chain or consumption scenario are variations on the moving average, Voronoi or Kriging techniques. Such a moving average enables the plotting of resources typically found in a given position and this type of analysis has been completed for biofuel supply to provide step changes in practice (Martindale, 2010). The blockchain approach can secure and scale this data so that models can be developed to ameliorate commercial risk such as for sugar beet where recent reports of sugar beet waste highlight the need to be ready for poor data reporting. The volumes of data required to predict and understand consumption are becoming attainable as open sources of information in on-line arenas. It is here where the data concerning consumption of products in populations provides important insights into how impacts are manifested in society. There are specific functions of food supply chains that have been identified and tested using geographic models to reduce business risks associated with investment, sustainability and security.

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4.1. Feedstock, transport and strategy; Martindale (2010), reported the use of the UK Agricultural and Horticultural Survey (AHS) in an analysis of feedstock production for bioethanol manufacturing. The primary feedstock was wheat where there were competitive supply chain functions with established bakery manufacturers. The analysis has provided accurate assessments of contingency for feedstock supply for biofuel, feed and food sectors and identified robust testing of GIS procedures. The models are what the industry has termed locality or ‘gravity analysis’ in that they provided an assessment of cereal and other crops produced within specific distances of each bioethanol manufacturing facility. Once this was achieved, LCA and resource input metrics for crops and livestock production systems could be included in the GIS assessments. This has extended the applications for the strategic planning of food transport costs and mass-flow in supply chains including GHG emissions and costs associated with transportation (**Figure, 1**).

Such analysis is shown in **Figure 1** and **Table 1,** for the sugar beet crop production and proximity to processing factories and animal manure sources. The sugar beet crop provides the feedstock for processing and manufacture of sugar at relatively few factories which means the model is streamlined. The spatial relationship of the UK sugar beet crop to major roads and processing factories are shown. Data extracted from the AHS is used to determine the amount of sugar beet and animal manure within 20 km of the factories which is crucial because organic manures are used in crop rotations when they are available and the economic cost of transporting them can be assessed from the model. The analysis shown in **Figure 1** and **Table 1**, demonstrate the Wissington factory has nearly double the area of sugar beet within 20 Km compared to Bury St Edmunds factory but there is double the organic manure resource within 20 km of the Bury St Edmunds factory.

The model shown in **Figure 1**, is used to assess what resources are located within specific areas of production and manufacture. These models can be developed to incorporate and project the transportation impacts. This has been achieved for the social and environmental costs in the sustainability planning for food and beverage businesses (**Table 2**). The models have taken a category approach in that the food companies investigated are segmented into

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dairy, confectionery and beverage categories. These can then be benchmarked across each other and potential risks to supply can be assessed. The analysis begins to assess the risk associated with the movement of food and beverage products which is of importance in developing biosecurity strategies. It can be developed further by considering population density and consumption models using data obtained from the National Census and National Dietary and Nutrition Survey. These have been developed and they are described here for developing the carbon and food waste footprint of diets for city regions in the UK.

Food system operators can be segmented into producers, manufacturers, distributors, retailers and consumers which is a helpful view of the food ecosystem. Complexity arises here because the network is composed of several supply chains and the number of these makes projecting the functioning of the food system incredibly difficult. The food system is not only defined by volumes of transactions because the requirements of customers are far more complex with environmental impact and social responsibility increasingly having a role. These are continually stimulating the demand for innovation in the food system and the research reported here has shown how measurements can be geocoded and new technologies such as the blockchain platforms can secure the integrity of supply chain information. This will help to identify knowledge-gaps in supply information and provide opportunities to implement more incisive consumer communications that are based on supply chain evidence.

4.2. Food supply and biosecurity; a GIS scenario developed for prepared meals and wheat supply chains are shown in **Figures 2a** and **b**. The prepared meals supply chain has been categorised to include vegetable, dairy, meat, poultry, seafood and dairy processors that supply ingredients. The wheat supply chain includes production data because the

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supply chain is effectively gated by the intensity of production and mills which process wheat into ingredients. It is a more straightforward situation than for prepared meals where there are several ingredient categories and processors. The food business geocoded models develop previous studies reported here that have been resource based because there is now a means to calculate risk of how much produce enters supply chains. The analysis of the geolocation enables the building of scenarios that can demonstrate the complete use of raw materials and recirculation of resources for circular economy solutions. The business location models enable the use of metrics such as those presented in **Table 2**, so that the transportation impact and sustainability of food products can be reported.

How the different food supply chain operators connect in **Figures 2a and b**, are of importance and these are assessed by calculating their connectance. The connectance for producers of dairy and meat in Great Britain using the fame business database are shown in **Table 3, 4 and 5,** where these are shown in **Figure 2a**, by geolocation. **Table 3**, shows the number of producers is greater than the number of manufacturers in each product category with the connectance value for meat supply chains being 2.63 fold greater than dairy supply chains because of a 3.29 fold greater number of manufacturers. **Table 4,** shows the connectance for condiment and seasoning ingredients is greater than that of dairy and meat producers because there are relatively few ingredients suppliers compared to the meat and dairy producers shown in **Table 3**. The supply chain summarised in **Table 3** and **4**, provide is an important case study where intermediate processors are required (seasoning and condiment manufacturers) and defining their connectance is of vital importance in food safety risk reduction (Marvin et al., 2016). **Table 5,** shows the connectance for cereal producers to mills and their connectance to manufacturers of cereals and baked products. The connectance values between producers and mills and mills to manufacturer are similar because the number of producers is similar to the number of manufacturers providing a

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relatively low connectance value for each. This is the classic funnel-in and funnel-out relationship where mills provide a link between producers and manufactures but the result in low connectivity due to each mill having several potential links.

The ability to stimulate the application of data in every food manufacturing business has been brought about by digitalisation where the use of mobile computers such as tablets and phones has made cloud computing a mainstay of commercial practice. This is the ability to scale, there is nothing mystical here even if the language associated with scaling tends to do this. A surface look at what companies have been doing in food and beverage shows that innovators have been using these practices to develop data integrity and traceability for at least a decade now (Francisco and Swanson, 2018). As an example, we have seen a rising interest in the reporting of the EC Rapid Alerts System for Food and Feeds (RASFF) and we need to associate this data to make it applicable to every food and beverage manufacturer (Tähkäpää et al., 2015). Data integrity has no boundaries here and it is a decrease of business risk in this space that defines the success of using these applications. Association techniques have also proven useful in presenting risk data for food supply and consumption using synteny methods which transform 'search and classify' informatics to those of 'association and projection'. It enables quantification of homologous data between datasets so that projections can be made to guide and futureproof biosecurity and food safety policy (Song et al., 2017b). Connectivity in food systems is also tested in such analyses and the assessment of supply chain connections is an aspect of projecting risk in biosecurity.

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5. Conclusion.

In this study we report the use of connectivity between supply chain functions where there is a need to identify control points where all major processing must occur e.g. in the case of small grains mills and crusher operations that all produce must go through. The results presented and discussed here have established a platform for delivering risk reduction models for the food system. The integration of blockchain platforms and Enterprise Resource Planning (ERP) platforms has made the data streaming of geolocation and geocoded models applicable to business ecosystem scenarios (Pearson et al., 2019). We are currently experiencing a digital revolution occurring in food supply where the ability to scale a digital application across supply chains is more practicable and accessible for all partners (Martindale et al., 2018a). The type of geographical analysis methods presented here are being integrated with current data streaming and blockchain platforms so that they are enhancing trust and sustainable integration of food supply chains. Most important is the fact that large amounts of supply chain data are held by suppliers and if it is possible to assimilate them in real-time analysis with logistical operations then the resulting commercial outcomes are strengthened (Song et al., 2017a). The requirement to provide such ‘concept to consumer’ approaches with food products has revolutionised what companies can achieve for allergen awareness, safety reporting and ingredient declarations. It has also started to be applied to sustainability reporting where it removes the taint of greenwash and it has the potential to change how bespoke nutritional information for specific consumers with exact metabolic or genetic requirements might be transferred. This is an area where secure data on provenance and blockchain approaches could help to eradicate illegal practices and there are proven solutions entering the food system especially if data is streamed and assessed *in situ*. The applications here demonstrate how securing physical and virtual data associated with food products can create trust cultures which are the most

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valued attributes that brands and companies can hold as assets, without them their value will disappear, without them sustainability is nothing more than aspirational.

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